August 1990

Thesis/Dissertation

Measurement of Visibility Through Spray

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MEASUREMENT OF VISIBILITY THROUGH SPRAY

A Thesis

by

BRUCE ALAN WRIGHT

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 1990

Major Subject: Industrial Engineering

MEASUREMENT OF VISIBILITY THROUGH SPRAY

A Thesis

by

BRUCE ALAN WRIGHT

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August 1990

ABSTRACT

Measurement of Visibility Through Spray. (August 1990)

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Chair of Advisory Committee: Dr. Rodger Koppa

This study attempts to predict the effect of visual impairment from simulated levels of splash and spray on target vehicle identification distances. Five levels of hand held spray simulation frames were used to compare image digitization methods with visual performance (Snellen acuity or contrast sensitivity) assessment to predict a drivers ability to identify an oncoming target vehicle. The image digitization process was found to be highly correlated with actual target vehicle identification distances. Additionally, very high correlations were found between Snellen acuity and contrast sensitivity and identification distance. There did not seem to be any great difference in predictive power of either method of visual performance assessment over the other.

ACKNOWLEDGEMENTS

I would like to thank Dr. Rodger Koppa for all his help in putting this thesis together, especially for giving me gentle guidance and sometimes a firm push when I needed it. I am also thankful for the helpful suggestions and editorial comments provided by Dr. R. Dale Huchingson and Dr. Waymon Johnston. I want to extend my sincere thanks to my wife Joanna, her red pen should be retired with honors, and to the Air Force for providing me with the opportunity to come to Texas A&M University for my Masters degree. Our cats Kathy, Miss Kitty, and especially Panther deserve special mention for making me take more breaks and unwind.

Mom and Dad, thanks to you, I finally made it.

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INTRODUCTION

The ability of an operator of a motor vehicle to detect hazards is very dependent upon one's visual performance, ambient lighting levels, and atmospheric conditions. If that person is not able to obtain enough information because of inadequate lighting, rain, splash and spray, or some subtle visual impairment, a hazardous situation could escape detection. Static visual acuity is one measure of visual performance, however good acuity, by itself, cannot guarantee that a driver will be able to detect hazards in less than optimal viewing conditions.

Guyton (1981) describes the standard method for determining a person's static visual acuity as the Snellen line system. This system is based on a carefully printed chart with lines of high contrast letters which decrease in size toward the bottom of the chart. The chart is placed twenty feet away from the observer who is asked to read lines corresponding to "normal" visual acuity for the population. The results of the test are recorded as a Snellen number which is simply the ratio of two distances - that of one's own visual acuity to that of the "normal" person under ideal circumstances. For example, if a person is able to see the small (five minutes of visual arc) high contrast letters normally visible at 6 meters, he/she is said to have $^6/_6$ vision. In a paper relating vision capability to performance, Ginsburg (1983b) describes the Snellen system as testing only the optical characteristics of the eye, specifically foveal acuity, and that it is primarily a measure of visual quantity (size), not quality (size

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and contrast). Another method of vision testing is the Contrast Sensitivity Function (CSF).

The CSF, a recently developed vision assessment technique, is very different in nature from the Snellen acuity testing and Owsley, Sekuler, and Boldt (1981) have shown it to be much more able to accurately predict real world visual performance under less than ideal conditions. The CSF is a curve that describes an observer's threshold sensitivity to targets of different sizes. Ginsburg in the Handbook of Perception and Human Performance (1986) provides the following definition:

> Contrast of a sinusoidal grating is the difference between its maximum and minimum luminances divided by their sum.

$$C = \frac{L_{max} - L_{min}}{L_{max} + L_{min}}$$

> For a constant luminance, the amount of contrast needed to detect a grating, contrast threshold, varies as a function of its spatial frequency. The reciprocal of the threshold contrast needed for detection is contrast sensitivity. A plot of log sensitivity as a function of log spatial frequency is known as the contrast sensitivity function.

The CSF is similar in function to an audiogram, which plots the performance of the auditory system. Sekuler and Blake (1985, ch. 6) describes the CSF as testing the whole visual system, stating that one is able to detect faults in the optics of the eye as well as in the neural processing of the image by interpreting abnormalities of the plot.

According to Ginsburg (1983b), the brain converts the retinal image into a visual code based on the shape and contrast of the target. He states: "The contrast sensitivity tests use contrast and single spatial frequencies to measure sensitivity to complex targets. This technique describes the general filtering characteristics of vision, visual capability and performance in a quantitative manner." Each spatial frequency provides a piece of information about an object in much the same way that different audible frequencies make up the sensation of sound. Conceptually, the contrast sensitivity function can be described as representing many filters and receptive fields grouped together in channels. A channel describes a set of neurons which are able to respond to targets over a narrow range of spatial frequencies. These channels are mostly independent from one another and each channel has a different sensitivity (see figure 1). Each curve, or channel, describes the points at which the contrast of an object at a particular spatial frequency is just visible, and moving down the plot will increase contrast to make the object more visible. If any of the channels are impaired, for whatever reason, a decrease in visual performance will be realized. Additionally, Ginsburg (1983a) concluded: "Contrast losses resulting from HUD optics (owing to transmittance, glare, and reflections) were translated into detection range losses using previously collected field trial data that related differences in aircraft detection range of Air Force pilots to differences in their contrast sensitivity." Another conclusion was that "...any factor which reduces target contrast reduces target detection and recognition range". As a result of these findings, research has turned toward measurement of differences in real world visual ability.

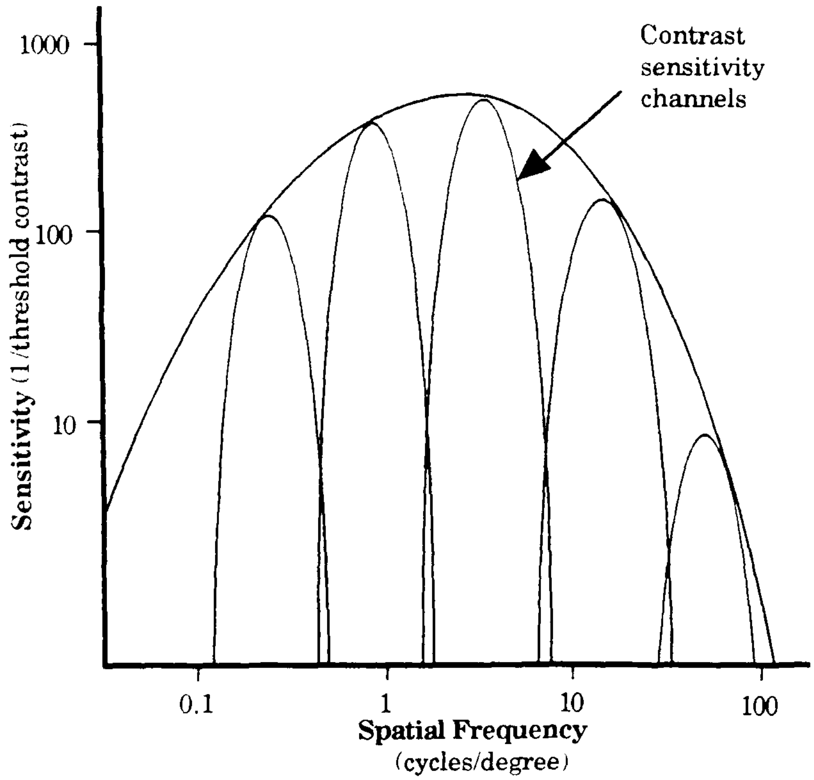

Figure 1. Contrast Sensitivity Channels

Evans and Ginsburg (1985) outline the application of the CSF to tasks of driving. It was shown that a random group of 20 drivers with $^6/_6$ visual acuity and ages ranging between 19 and 79 years displayed significant differences in the distances at which they were able to discriminate highway signs. The older group of subjects had significantly lower contrast sensitivity in certain spatial frequencies and they required a significantly larger symbol to determine if it denoted a four way "+" intersection or a "T" intersection (figure 2). The correlation between Snellen acuity and discrimination distance was <u>not</u> significant.

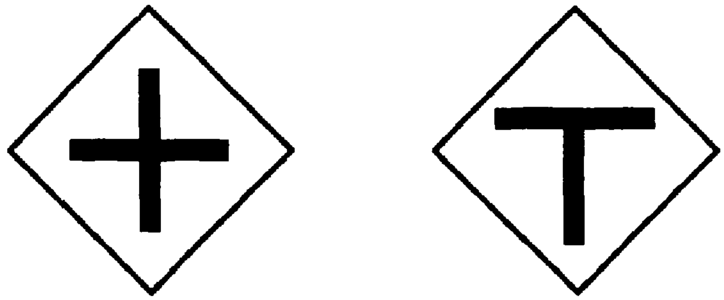

Figure 2. Highway Signs

The most recent method of visibility assessment, obtained through the digitization of videotaped images resulting from some obscuration, was described by Koppa and Pezoldt (1990). Appendix A describes in detail the relationship between laser percent transmission and the digitized videotape image Coefficient of Variation (CV). In general, a laser is used to excite a photodetector to measure light transmission over a specified distance based on zero (no light) and 100% (full illumination) calibrations prior to each run. The digitization process encodes an analog image by brightness into a file with numbers between 0 (dark) and 256 (white).

When the data from a digitized image file is plotted, the frequency distribution of brightness of a black/white (strong contrast) image such as a checkerboard has a bimodal distribution. The peak near the high end of the range of pixel brightness corresponds to the white checkers, and the peak at the lower end of the range corresponds to the black checkers. When some diffusing substance like a cloud or mist is interposed between the camera and the checkerboard, the resulting array of pixel brightnesses change, because the strong contrast of white and black checkers is greyed out. Hence the distribution changes shape and even begins to look like a bell-shaped curve with a mean brightness somewhat

below the bimodal mean, and a much smaller standard deviation.

In order to express these graphic images mathematically, a Coefficient of Variation (CV) was employed. The CV is simply the standard deviation of brightness divided by its mean or average. The ratio of an experimental CV and the baseline CV multiplied by 100 yielded a Figure of Merit (FOM) analogous to the percentage of laser transmittance. The digitization results provided the following regression equation:

$$\text{Digitize (CV)} = 0.72(\text{Laser percent transmission}) + 8.09$$

A correlation of 0.85 was obtained between the laser percent transmission and digitized values of the same runs where 1.00 corresponds to a perfect relationship, and 0 to no relationship at all.

The above references have shown that light transmissivity losses due to media in front of the eye (e.g., fog, rain, or spray) or resulting from deficiencies within the eye may be quantified using various visual assessment techniques. In this study, decreases in target identification distance were related to visual acuity changes induced by spray simulations.

Objectives

The objectives of this study were:

1. Relate two measures of visual performance (visual acuity and contrast sensitivity) in the laboratory to subjective field measures (target identification distance) at simulated levels of visibility.

2. Relate digitized images of targets videotaped through various levels of spray to simulated levels of obscuration.

3. Determine which measure of visibility (Figure of Merit) or visual performance (Snellen acuity or contrast sensitivity) better relates to a driver's ability to identify an oncoming target in real-world situations.

METHOD

Independent variable

The independent variable in this study was the level of visual degradation imposed by simulated spray frames.

Measures

The dependent variables were the target detection distance, changes in the Snellen visual acuity, and CSF measures of visual performance through each level of simulated spray.

Participants

A total of 20 (12 male and 8 female) individuals participated in this experiment. The volunteer subjects were students or staff from Texas A&M University or associates of the experimenter. The younger group of 9 males and 7 females ranged in age from 22 to 40 years, the mean was 30.75 and the standard deviation was 5.29. The older group of 3 males and 1 female ranged in age from 59 to 64 years, the mean was 61.5 and the standard deviation was 2.08. Each subject possessed a valid drivers license, was in good health and free from any gross visual pathology. The experimenter determined the Snellen visual acuity and a CSF for each subject prior to field trials.

Apparatus

Several methods of simulating splash and spray obscuration were evaluated. A spray simulation was chosen because of the difficulties

involved in accurately reproducing a given level of spray in an uncontrolled environment. It was judged that clear acetate document protectors adequately approximated the visual effect of splash and spray when viewing roadway scenes. A series of five 20 x 25 cm frames (designated s1 to s5) were built with one, two, four, six, or eight layers of acetate, respectively, sandwiched between two layers of glass. The visual effect of seeing through each of these frames was then digitized using a technique which was developed in another study (Koppa and Pezoldt, 1990) described in the introduction.

The resulting values for brightness obtained by Koppa and Pezoldt are summarized in the table on page 14. It should be noted that the brightness did not drop off very much as the obscuration increased, however the standard deviation indicating the level of contrast was reduced very rapidly. The resulting FOM for each of the frames related to how little visual information was actually transmitted through the frame to an observer's eyes or camera. This data was very representative of the effect the frames had on both measures of visual acuity as well as the target detection distance.

The laboratory phase of the experiment required that the visual acuity for each participant be tested with a wall mounted Snellen chart (Figure 3) at 6 meters (while wearing corrective lenses if appropriate). Additionally, contrast sensitivity was measured at five spatial frequencies (86, 172, 344, 688, and 1032 $^{cycles}/_{radian}$) using the Vistech VCTS 6500 wall mounted chart (Figure 4) at the recommended distance of 3 meters. Luminance for each test procedure was normal room lighting (103-240 $^{cd}/_{m^2}$). These measurements were repeated while the subject looked

through each of the five simulated spray levels and all information was transcribed to the Lab Data Sheet (Appendix B).

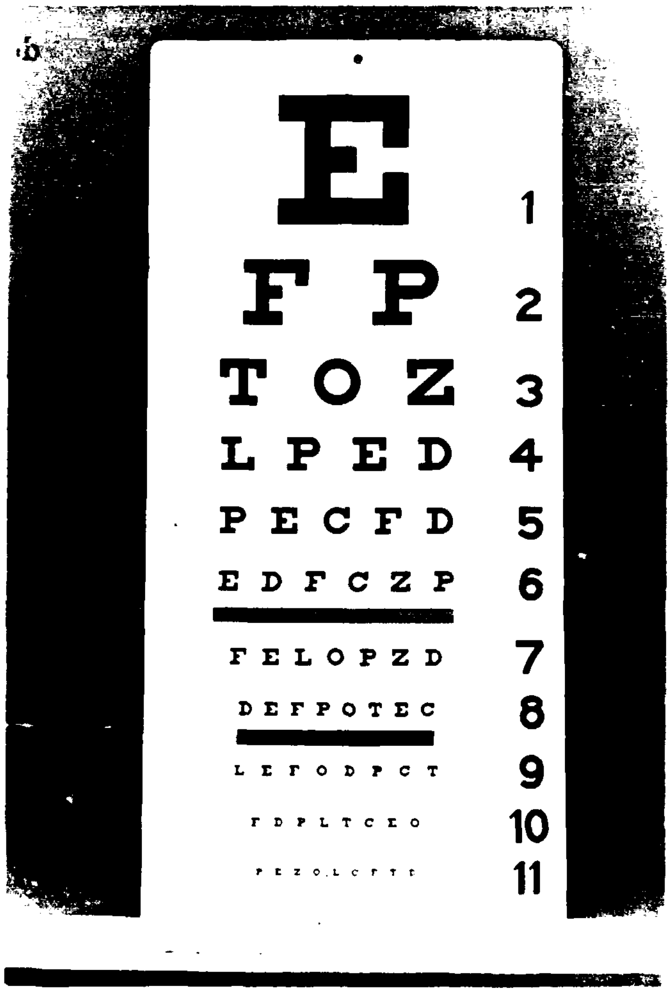

Figure 3. Snellen Chart

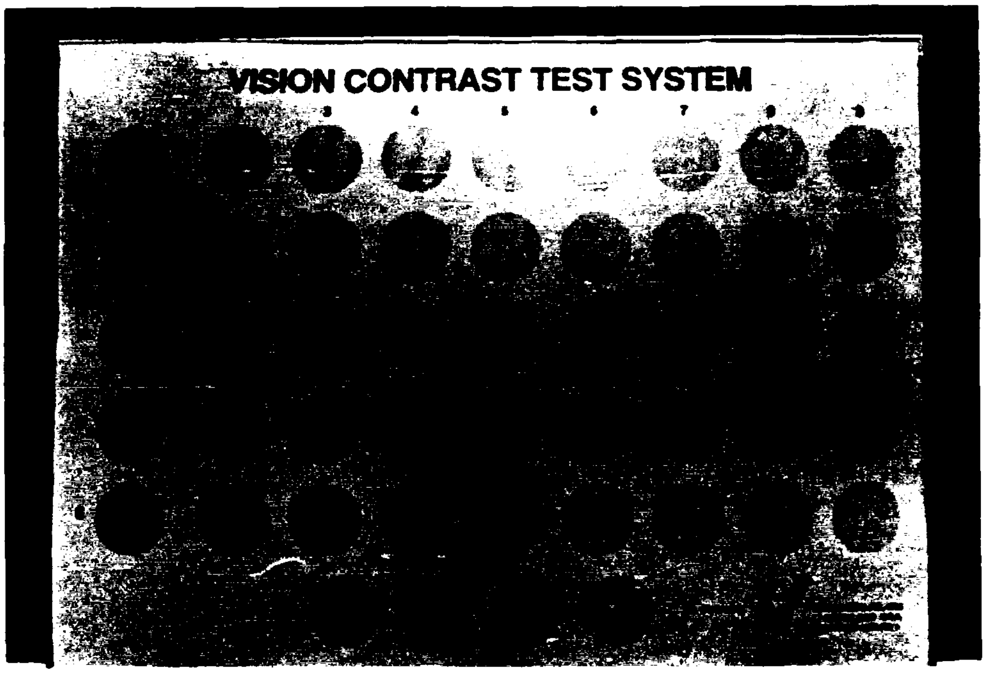

Figure 4. Contrast Sensitivity Chart

The field trial phase of the experiment required that the subject be seated in a stationary automobile (a 1978 Oldsmobile Cutlass Salon) at a designated spot on the runway. The target automobile, a brown 1979 Pontiac Grand Am (Figure 5), was situated on the runway 1610 meters from the stationary car. The target vehicle was equipped with a fifth wheel and a digital distance display on top of the instrument panel (Figure 6). Hand held radios were carried in each car in order to report experimental information during the trial. The driver of the target vehicle recorded the distance traveled at each sighting on the Field Data Sheet (Appendix C).

Figure 5. Target Vehicle

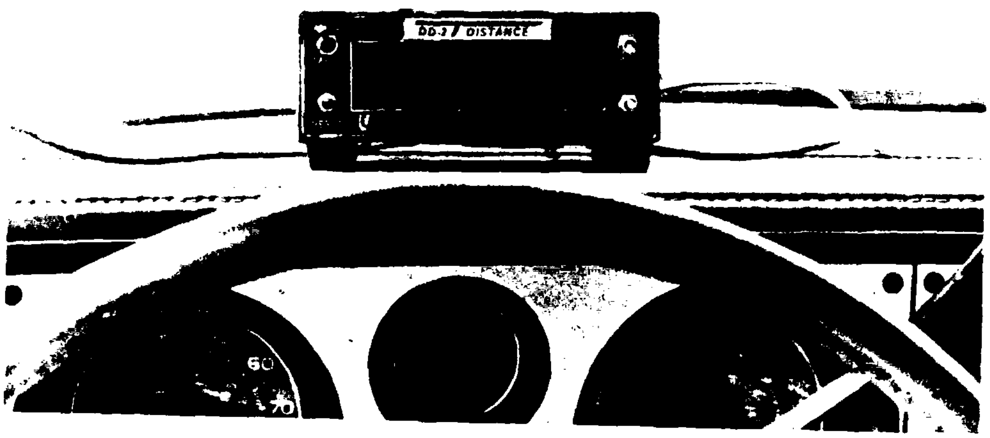

Figure 6. Digital Distance Display

Procedure

Each participant met the experimenter at the drivers education classroom on the Texas A&M Riverside campus for the laboratory portion of the trial (Appendix D). Subjects were assigned identification numbers for experimental purposes as they completed the Participant Information Form (Appendix E). All participants were briefed on the methods and risks associated with the test procedure from the Subject Briefing Narrative (Appendix F). Next, visual acuity was measured with a standard Snellen eye chart, and contrast sensitivity was measured with the Vistech wall mounted chart following recommended test procedures. Each subject was comfortably seated at the appropriate distance and both measures repeated for each level of simulated spray. Each frame was held approximately 15 cm in front of the eyes and the results were immediately recorded on the Lab Data Sheet.

After the laboratory measurements were recorded, the field trials were performed on a 2135 meter runway at a former Air Force Base now known as the Texas A&M Riverside Campus. All trials took place between 9:00 A.M. and 4:00 P.M. under cloudy conditions to reduce variations in ambient lighting. The experimental procedure was the method of limits and each trial was sequenced through five increasing magnitudes of simulated spray and a control. Each subject was seated in the Cutlass at a pre-determined site on the runway. The windshield of the car and the glass in the frames were inspected before the trials to ensure they were clean.

Upon receiving an appropriate radio signal, the target vehicle started toward the subject from a distance of 1610 meters and advanced at

16-24 KPH until the subject indicated he/she could identify it as a car. As the target car approached the subject from the opposite end of the runway, the subject was instructed to report by radio when he/she could discern the target vehicle first as an object, then identify it as a car. The experimenter in the target vehicle would stop and record the distance traveled as soon as the subject identified the target vehicle as a car. While the target vehicle was stopped, the subject would hold the first simulated spray frame about six inches in front of their eyes. The next radio message from the subject car would state whether the target car was seen as an object, then the target car would advance until it could be identified as a car again. If the subject could not identify the car as an object while it was stationary, the subject had to report when the car became an object as it moved forward. However, nearly every frame change resulted in an immediate report of the target car being an object. The start and stop procedure continued until there were no higher levels of spray and the whole process was repeated three times with the results being averaged and then subtracted from 1610 in order to obtain actual detection distances.

RESULTS

Snellen visual acuity data

The average Snellen visual acuity for the subject group was $^6/_5$ although the range was between $^6/_4$ and $^6/_8$. The Snellen ratio was reduced to a decimal value for purposes of evaluation (Table 1). A plot of the resulting Snellen visual acuities for each frame is shown in Figure 7. As it can be seen, the average Snellen value decreased dramatically with increasing obscuration and the standard deviation decreased as well. The author had expected a more rapid drop in Snellen acuity with the top line ($^6/_{60}$) becoming unresolvable by slide s4. On the contrary, subjects were able to make out the fuzzy images reasonably well, and some were even able to read the $^6/_{30}$ line through frame s5. Each frame produced a drop in acuity of at least one Snellen line and several subjects were not able to see the top ($^6/_{60}$) line of the chart through s5. These data points were recorded as $^6/_{120}$ for computational purposes.

Contrast sensitivity data

The Contrast Sensitivity test produced a set of numbers (1-9) corresponding to the subject's sensitivity in each of five spatial frequencies (row A through E). The sum of those five values was chosen to represent a CS score (Sum CS) for purposes of evaluation (Table 1). The average sum of CS scores for the subject group was 30.15, although the minimum was 24 and the maximum was 35. The highest spatial frequencies (bottom rows of the contrast sensitivity chart) were the first to be degraded by the frames. The lowest spatial frequency (top row) was the

TABLE 1

Frame Results Summary

frame	Brightness Digitization				Distance		Snellen		Sum CS	
level	mean	S.D.*	CV	FOM	mean	S.D.*	mean	S.D.*	mean	S.D.*
base	142.46	60.53	0.42	1.00	1110.8	308.39	1.258	.258	30.15	3.41
s1	143.3	36.64	0.26	0.60	905.01	301.98	.828	.149	21	2.88
s2	138.31	25.38	0.18	0.43	622.88	231.08	.491	.172	14.95	2.11
s3	114.35	12.5	0.11	0.26	329.62	153.24	.288	.074	9.4	1.9
s4	102.36	7.14	0.07	0.17	106.93	52.44	.145	.051	3.05	0.88
s5	93.75	6.01	0.06	0.15	48.21	22.16	.072	.025	0.6	0.59

* = Based on (n-1)

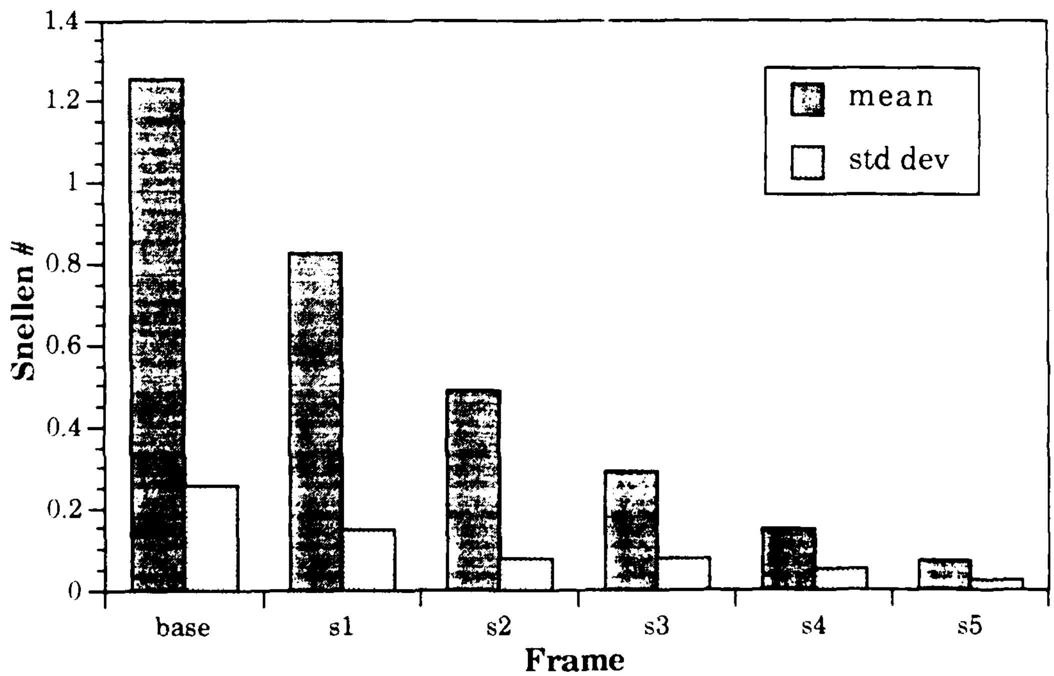

Figure 7. Snellen Visual Acuity by Frame

least affected by the frames. A plot of the resulting Contrast Sensitivity scores for each frame is shown in Figure 8. Here it can be seen that the available contrast through each consecutive frame was highly reduced and the standard deviation was reduced as well. This is what the author had expected and closely approximates the results of Evans and Ginsburg (1985) study of highway sign discriminability. The loss of high spatial frequency sensitivity brought about impairment of target detection ability at longer distances.

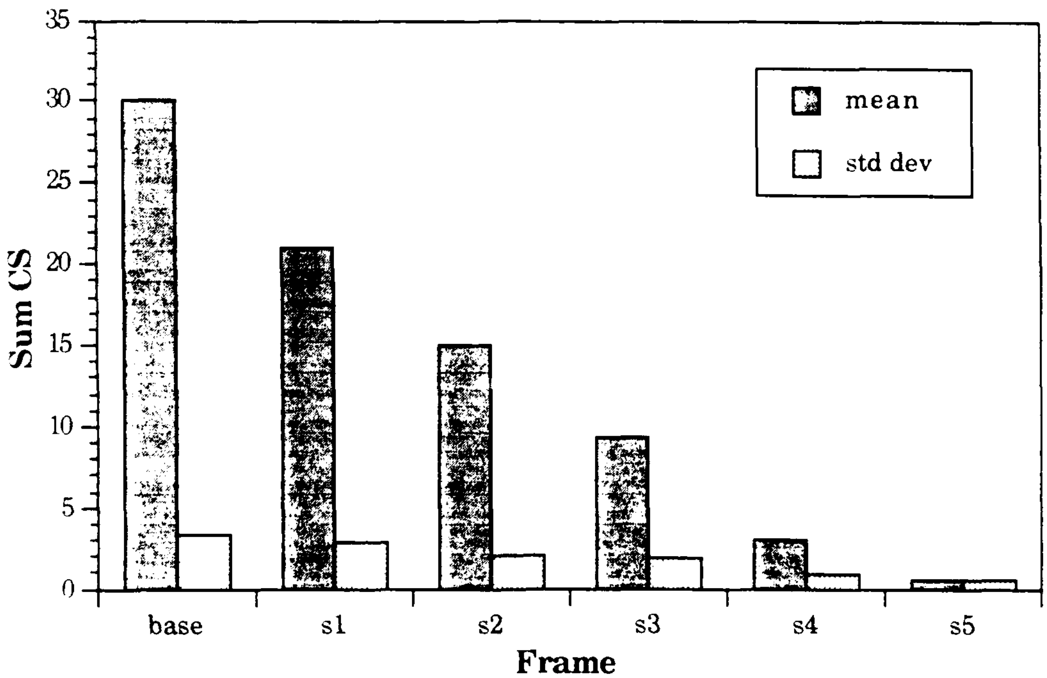

Figure 8. Contrast Sensitivity Score By Frame

Identification distance data

The average baseline identification distance for the subject group was 1110 meters. The minimum identification distance was 584 meters, and the runway length limited the maximum to 1610 meters. Table 1

summarizes the mean and standard deviation for each of the frames with respect to target identification distances. A plot of the resulting identification distances for each slide is shown in Figure 9. As it can be seen, there were large decreases in detection distances for each slide and the variability among the reported distances for each slide decreased as well. The effect of age on target identification distance was <u>not</u> significant. The small sample size of the subject population is the most likely causes of this lack of significance. One additional factor which could not be effectively controlled was the criteria each subject used to judge the target vehicle as a car. It was obvious that some subjects did not need much visual information to call the image a car, while others required much greater amounts of information before making the call. This is reflected in the rather large standard deviations reported in Table 1. Each subject was instructed to maintain the same judgement criteria for calling the target a car throughout the trials, but the criteria were certainly different with different subjects.

Identification distance vs. visual performance regression data

The first objective of this experiment was to relate laboratory visual performance to target identification distance. A regression analysis was performed to determine that relationship. Both the Snellen and Sum CS Correlation Coefficients have shown a very high association with the response variable (identification distance). The author had expected a high correlation for the contrast sensitivity measure but the high correlation for the Snellen numbers was somewhat surprising. It is difficult to see any real difference in the predictive power of either

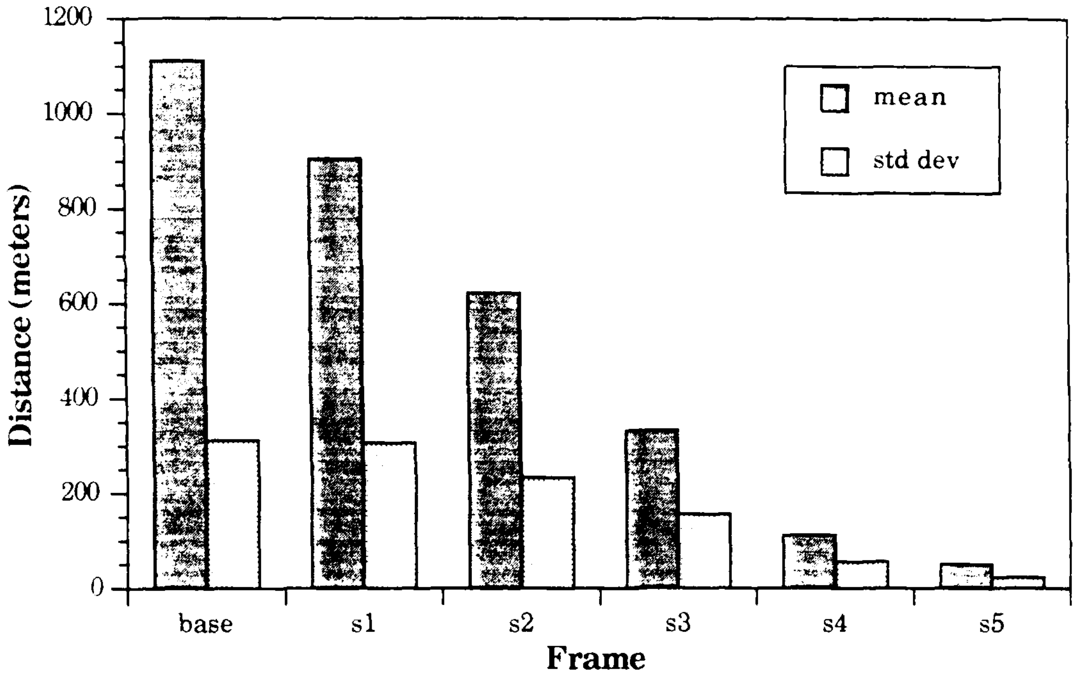

Figure 9. Identification Distances By Frame

measure of visual performance. Indeed, the following tables and figures of the Snellen and CS regressions show a striking resemblance to one another. Each measure produced nearly identical Correlation Coefficients and the scatter plots of distance against Snellen or Sum CS are nearly indistinguishable. Figure 10 is a scatter plot of the identification distances against Snellen acuity with the regression line fitted. Table 2 summarizes the regression output for identification distance vs. Snellen number. It is clear that the Snellen measure was highly associated with the identification distance ($r = 0.891$). The computed equation for the Snellen regression line is:

$$\text{Identification distance (meters)} = 911.916(\text{Snellen number})$$

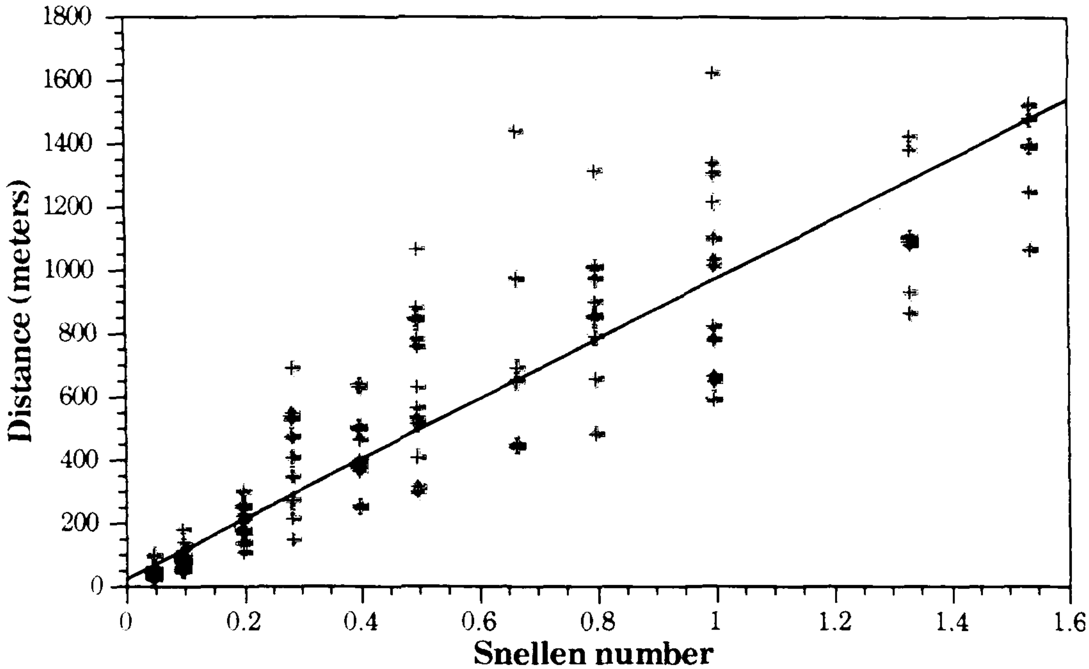

Figure 10. Identification Distance vs. Snellen Number

TABLE 2

Linear Regression, Detection Distance vs. Snellen Number

Linear Summary of Fit	
Rsquare	.795
Root Mean Square Error	202.914
Correlation Coefficient	.891
Mean of Response	521.591
Observations (or Sum Wgts)	120

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	52.824	28.691	1.84	0.0681
Snellen	911.916	42.622	21.40	0.0000

Figure 11 is a scatter plot of the identification distances against Sum CS with the regression line fitted. Table 3 summarizes the regression output for identification distance vs. contrast sensitivity. This measure was also very highly correlated with target identification distance ($r = .889$). The computed equation for the Sum CS regression line is:

Identification distance (meters) = 37.847(Sum CS)

As far as the third objective of this study is concerned, the only apparent difference in the two visual assessment techniques is the time it takes to administer them, with the Snellen test taking less than half the time of the CS test. There does not seem to be any great advantage in one test over the other in predictive power of target identification distance.

Figure of merit data

Identification distance was highly correlated ($r = 0.849$) with the results of the digitization output (FOM) shown in Table 4. A scatter plot of that relationship is presented in Figure 12. The regression equation for this relationship is:

Identification distance = 1272.279(Figure of merit)

Both measures of visual performance are very highly correlated with the digitization processes resulting Figure of Merit (FOM). The correlation ($r = 0.950$) between the Snellen number and FOM through the frames is shown in Table 5 and the associated scatter plot is presented in

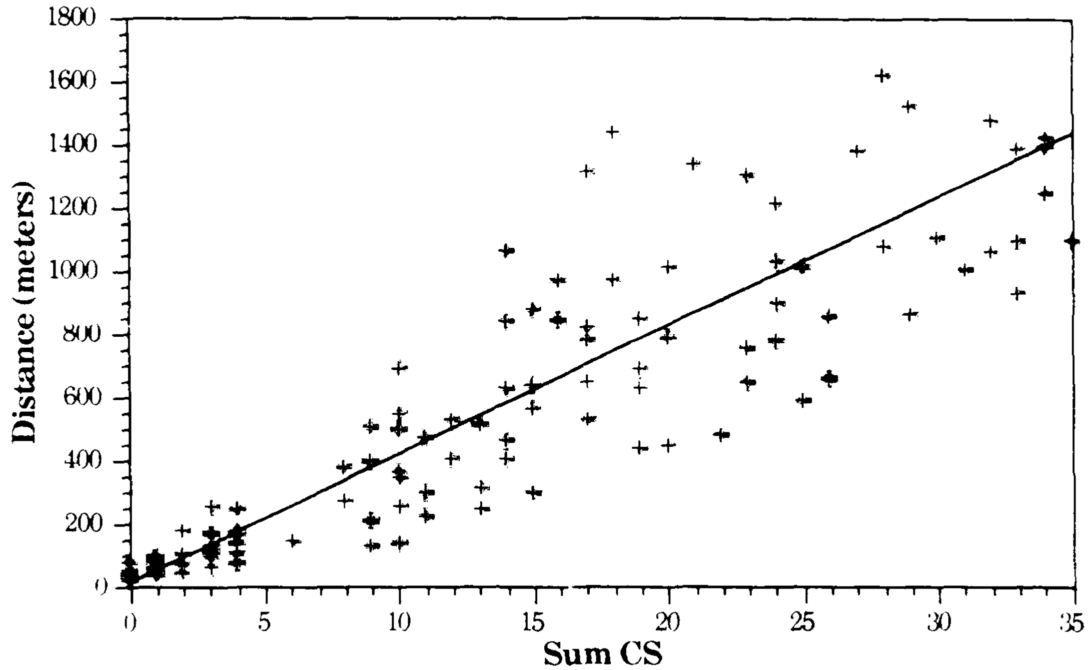

Figure 11. Identification Distance vs. Contrast Sensitivity Score

TABLE 3

Linear Regression, Detection Distance vs. Contrast Sensitivity

Linear Summary of Fit	
Rsquare	.792
Root Mean Square Error	204.583
Correlation Coefficient	.889
Mean of Response	521.592
Observations (or Sum Wgts)	120

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	22.328	30.077	0.74	0.4594
Sum CS	37.847	1.787	21.18	0.0000

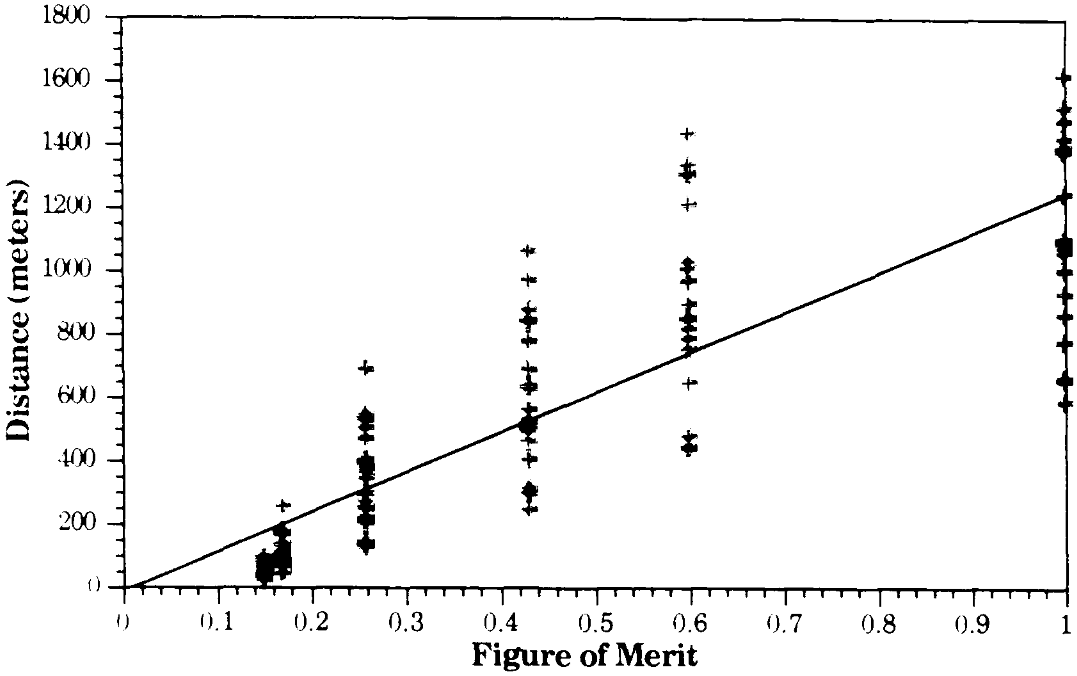

Figure 12. Identification Distance vs. Figure of Merit

TABLE 4

Linear Regression, Identification Distance vs. Figure of Merit

Linear Summary of Fit	
Rsquare	.722
Root Mean Square Error	236.425
Correlation Coefficient	.849
Mean of Response	521.591
Observations (or Sum Wgts)	120

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-31.846	38.293	-0.830	.4073
FOM	1272.269	72.717	17.50	0.000

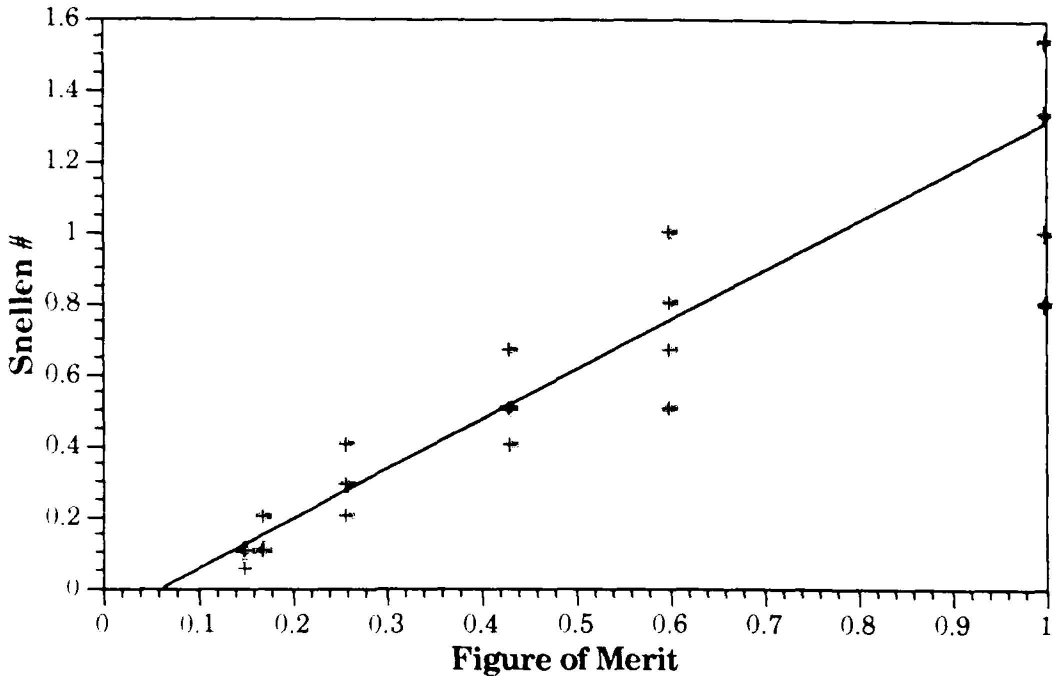

Figure 13. Snellen Number vs. Figure of Merit

TABLE 5

Linear Regression, Snellen Number vs. Figure of Merit

Linear Summary of Fit	
Rsquare	.903
Root Mean Square Error	.136
Correlation Coefficient	.950
Mean of Response	.514
Observations (or Sum Wgts)	120

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-.091	.022	-4.13	0.0001
FOM	1.392	.042	33.17	0.0000

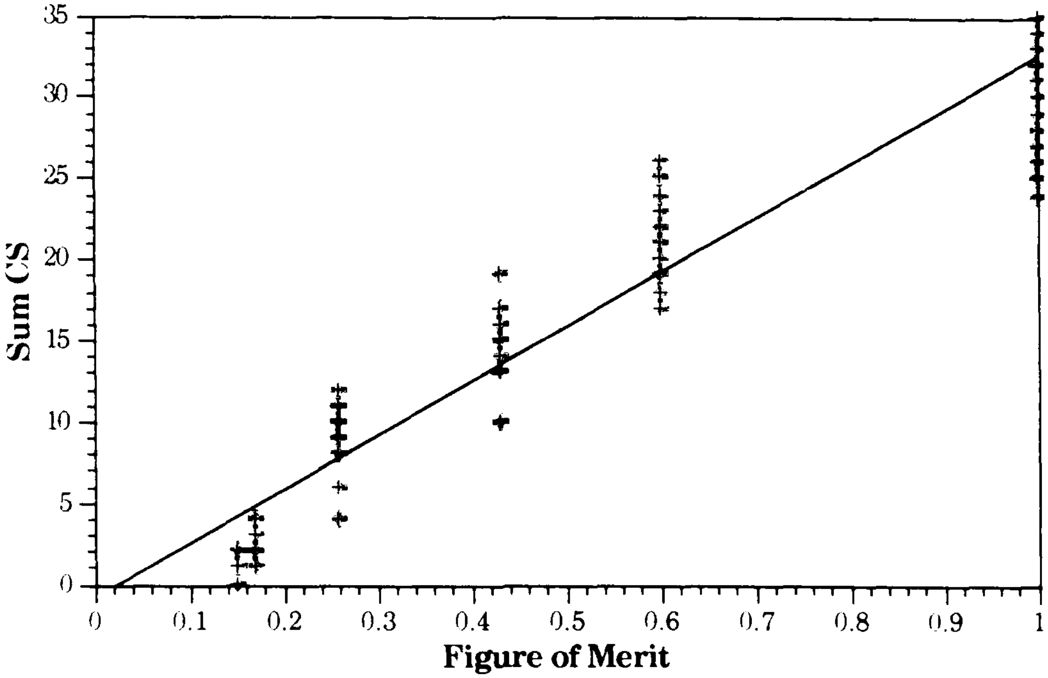

Figure 14. Contrast Sensitivity Score vs. Figure of Merit

TABLE 6

Linear Regression, Contrast Sensitivity Score vs. Figure of Merit

Linear Summary of Fit	
Rsquare	.915
Root Mean Square Error	3.070
Correlation Coefficient	.956
Mean of Response	13.191
Observations (or Sum Wgts)	120

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-1.458	.497	-2.93	0.0040
FOM	33.678	.944	35.66	0.0000

Figure 13. The computed equation for the relationship between Snellen and FOM is:

Snellen number = 1.3916(Figure of merit) - 0.091

The correlation (r = 0.956) between the Sum CS and FOM through the frames is shown in Table 6 and its associated scatter plot is presented in Figure 14. The computed equation for the relationship between Sum CS and FOM is:

Sum contrast sensitivity = 33.678(Figure of merit) - 1.458

All of the measures of brightness or visual performance are highly correlated with one another. The Figure of Merit is an electronically generated scale of relative brightness and contrast while the Snellen number represents more of a measure of size resolution for the eye, and the Sum CS is a measure of the eye's overall sensitivity to contrast over a particular range of spatial frequencies. It is gratifying to see that each of these methods for predicting target identification distances is well correlated with the others. If needed, laser percent transmission or a Figure of Merit may be used to predict visual acuity or contrast sensitivity as well as to determine potential target identification distances. The real advantage of this variety of predictive tools is in having the flexibility of employing whatever method is most suitable to the demands of the study.

CONCLUSIONS

The simulation of the visual effect produced by splash and spray by layering acetate document protectors was very successful. It seems that any matter which partially obstructs the clear viewing of a target will produce measurable decreases in visual acuity and this may be used to study target identification distances under less than ideal road conditions.

The correlation of both Snellen and Contrast Sensitivity measures with actual performance was great enough to warrant their use in future research into visibility impediments, such as heavy truck splash and spray. Since both vision assessment techniques were found to be very accurate in predicting target detection distance, the choice of a vision assessment method to use in future studies should be dictated by the availability of test equipment and time available for testing rather than any innate superiority of testing method. Further refinement of the target would probably gain even more accuracy. Specifically, if the target was simpler in its component spatial frequencies, there might be greater predictive power from the CS measure.

This research has supported earlier studies which demonstrated the validity of a video digitization method which can directly relate visibility through a spray cloud to a particular FOM. Researchers can confidently take CV ratios from transmissiometer readings or digitized videotape of spray or fog and relate them directly to target detection distances.

RECOMMENDATIONS

The video image digitization procedure and the resultant FOM used in this experiment provide an easy to use metric for comparisons of visual obscuration. Simple visual acuity tests may then be used to assess decrements in target discrimination. These techniques may then be applied to several areas of research, such as:

1. Evaluation of light losses through head up displays (HUD).
2. Evaluation of relative effects of window tinting films.
3. Evaluation of relative merit of traditional sunglasses vs. blue-blocker (amber) sunglasses.
4. Evaluation of the optical characteristics of embedded-wire heating element windshields.

Moreover, any area of research which investigates the effects of partial scattering of light on operator performance could benefit from the relatively simple techniques presented in this thesis. Further investigation into the relationship between each spatial frequency and target identification distance could provide future studies with even greater accuracy.

This study should be replicated with simpler target shapes which could be more easily described in terms of their spatial frequencies over the anticipated range of identification distances. Additionally, future studies should control lighting conditions more precisely (perhaps at twilight). The results of this and any follow on studies using these techniques should be validated in a comparison with existing visibility measuring equipment such as Runway Visual Range (RVR).

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APPENDIX A

LASER PERCENT TRANSMITTANCE AND IMAGE DIGITIZATION

Excerpts from: Koppa, R., and Pezoldt, V. (1990). <u>Development of a recommended practice for heavy truck splash and spray evaluation</u> (Tech. Report, Project RF7143). College Station: Texas A&M University, Texas Transportation Institute.

2.1 Variations from Established Practice

...The laser transmissiometers are in the same location they have been since 1986, parallel to the test surface, with lasers [5 $^{mw}/_{cm^2}$ power] and photocells [essentially light meters] spaced 50 feet apart. The checkerboards originally used in 1984 have returned to the setup, although they have been moved from just uprange of the photocells to 100 feet downrange from the photocells. During the course of the project they were moved several times, in order to assure that the shadow of the vehicle did not fall on the checkerboards and ruin the image digitization process. These checkerboards preclude visual estimates of the amount of spray that in one form or another were used in previous tests. The checkerboards block the view of the target at a distance as described by Koppa and Pendleton (1987). Hence the chase car with on-board observers was not used in this study.

Another change ... is the use of a digital computer to manage and reduce the data from each run, very shortly after the run is complete. The laser photocell outputs and outputs from the wind sensors are amplified and then go through an analog-digital conversion board in the small (8088 processor) personal computer that has been dedicated to splash and spray testing. A program in BASIC developed by R. A. Zimmer samples output at the rate of 25 seconds during a test interval with is initiated by the test

vehicle interrupting an infrared beam at the extreme uprange end of the 450 foot test surface. The computer times out 4 seconds later when the vehicle is clear of the test surface. Thus 100 observations are made of the sensor's output during the test interval. The laser transmissiometers are automatically calibrated by the test conductor's inputing a control character just before the vehicle breaks the IR beam. The calibration process consists of occluding the laser by means of a shutter, with the resulting low voltage output from the photocell designated 0 transmittance. When the shutter is opened and the beam thus unobstructed, the computer assigns the value 100 percent to the high voltage reading from the photocell.

After the test run, the computer writes the entire file of 100 observations to disk, together with time and date. Input on temperature, humidity, and vehicle speed is added by the test conductor. The program also provides summary information on the run. This consists of the lowest transmittance for each laser, with the wind direction and velocity at the calculated moment at which the vehicle reaches the laser beams. The file is in standard ASCII format, suitable for analysis by any standard statistical package.

2.2.5 Video Image Digitization

One objection to laser transmissiometer readings which has always been voiced is the very narrow beam which samples only a small fraction of the total spray cloud. Four sensors provide four very small samples of the cloud from which a generalized statement about the splash and spray performance of the vehicle must be made. A method for extracting data

about the entire cloud which results in quantifiable measurements would appear to be very desirable, to either replace or supplement the laser setups. Also, lasers are delicate and temperamental, require a regulated power supply, and must be aligned very accurately.

Inspired by paper by Luyomba and Sheltons (1987), considerable effort was launched by TTI early in 1989 to develop a capability to extract information from a digitized television image of the spray cloud against a reference background. The 1984 MVMA tests used checkerboard reference surfaces to make both still and motion pictures of the spray cloud, but these data provided only qualitative area type information about splash and spray. Texas Transportation Institute funded an R&D effort by the Machine Vision Laboratory of the Texas Engineering Experiment Station to develop the necessary hardware and software to obtain a Figure of Merit analogous to the minimum laser transmittance which has been used for each sensor's response to the spray cloud during a run. The process begins with the 30 frame-a-second record made by an analog video cassette recorder. The camera feeding the signal is adjusted to disable automatic gain control (which essentially acts to optimize contrast, and thus defeats the purpose of image digitization to evaluate <u>loss</u> of image contrast).

The program (written in C for the 386 personal computer) is capable of storing six frames at any given time as an array of numbers corresponding to pixels, which are the "grain" in a television image. Each pixel brightness and location is stored as a separate entry. The analog frame image is grabbed by an A to D board, reduced to the array, and stored to memory. The brightness of each pixel is encoded by a

number between 0 (dark) and 256 (white). When the file of pixels is plotted in a frequency distribution by brightness, a black/white strong contrast image such as a checkerboard looks like a bimodal distribution, as sketched in Figure A. There is a peak near the white end of the range of pixel brightness, corresponding to the white checkers, and another peak at the lower end of the range, corresponding to the black checkers. This distribution can be characterized by its mean or average pixel brightness value, and by the standard deviation or root-mean-square error around that mean value. If some substance like a cloud or mist is interposed between the camera and the checkerboard, the resulting array of pixel brightnesses changes, because the strong contrast of white and black checkers is greyed out. Hence the distribution changes shape and even begins to look like a bell-shaped curve with a mean brightness somewhat below the bimodal mean, and a much smaller standard deviation (Figure B). Thus the mean and standard deviation of a baseline high contrast image can be compared in some way with the mean and standard deviation of the same image obscured by a spray cloud to derive a figure of merit that says something about the quantity of spray being produced.

3.3 Image Digitization vs. Laser Transmissiometer

After many different approaches to deriving a figure of merit (FOM) from the data generated by the image digitization procedure briefly outlined in Section 2.2.5, the following rationale was developed. Since both the mean and the standard deviation change as the amount of spray interposed in the picture changes in density, a little-used quality control statistic known as the Coefficient of Variation (CV) was used as the

quantity from which the Figure of Merit (FOM) was derived. The CV is simply the standard deviation divided by the mean or average. The ratio of the two CV's multiplied by 100 yields a FOM analogous to the percentage of laser transmittance. A correlation analysis (linear regression) between the two measures on the same runs yields a very high product moment correlation of 0.85 where as 1.00 is a perfect relationship, and 0 is no relationship at all. The two measures are evidently responsive to the same phenomena in the same way! The plot of the data and the associated analysis is provided in Figure 15 and Table 7 respectively.

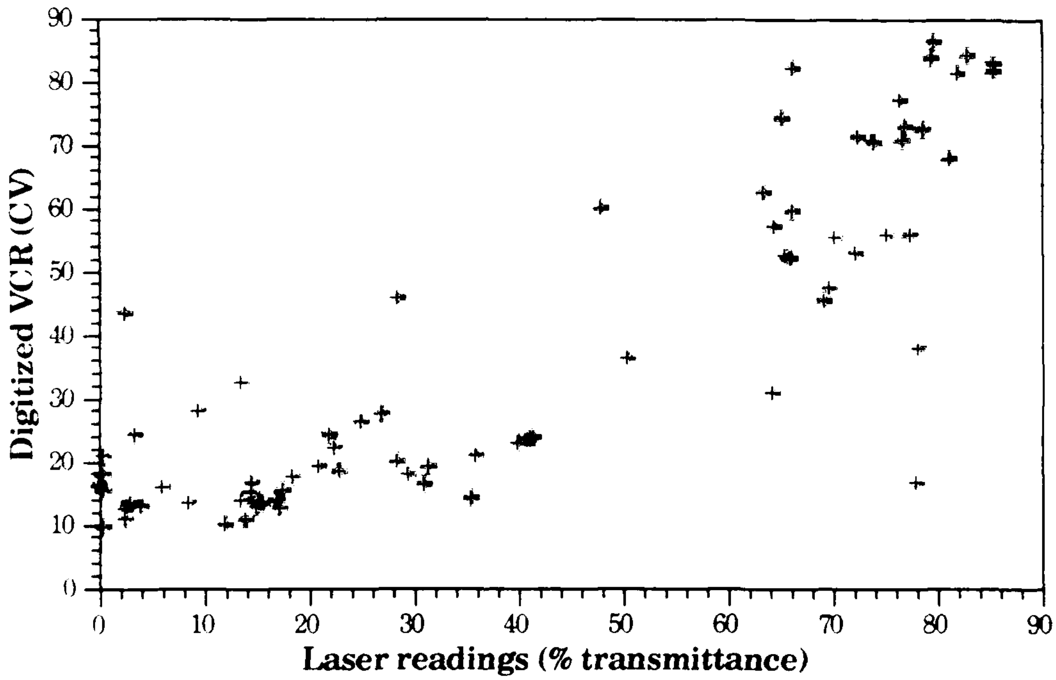


Figure 15. Digitization vs. Laser Percent Transmission

TABLE 7

Digitization vs. Laser Percent Transmission

Linear Summary of Fit	
Rsquare	.733
Root Mean Square Error	13.085
Correlation Coefficient	.856
Mean of Response	37.351
Observations (or Sum Wgts)	73

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	33314.206	33314.2	194.579
Error	71	12155.996	171.2	Prob > F
C Total	72	45470.202		0.0000

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	8.085	2.598	3.11	0.0027
Laser	.724	.052	13.95	0.0000

REFERENCES

Koppa, R., and Pendleton, O. (1987). Splash and spray test results (Tech. Paper 872279). Pennsylvania: Society of Automotive Engineers.

APPENDIX B

LAB DATA SHEET

Date ____________ Subject number ________

Contrast Sensitivity

Base line	Contrast level							
Row	1	2	3	4	5	6	7	8
A								
B								
C								
D								
E								

Slide 1	Contrast level							
Row	1	2	3	4	5	6	7	8
A								
B								
C								
D								
E								

Slide 2	Contrast level							
Row	1	2	3	4	5	6	7	8
A								
B								
C								
D								
E								

Slide 3	Contrast level							
Row	1	2	3	4	5	6	7	8
A								
B								
C								
D								
E								

Slide 4	Contrast level							
Row	1	2	3	4	5	6	7	8
A								
B								
C								
D								
E								

Slide 5	Contrast level							
Row	1	2	3	4	5	6	7	8
A								
B								
C								
D								
E								

Snellen Acuity

Base	Slide 1	Slide 2	Slide 3	Slide 4	Slide 5
20/	20/	20/	20/	20/	20/

APPENDIX C

FIELD DATA SHEET

Test date ______________ Subject number ______________

Sky conditions: Sunny Pt. cloudy Cloudy

Trial 1

Viewing Condition	ID as object (feet)	ID as car (feet)
BASE		
SLIDE 1		
SLIDE 2		
SLIDE 3		
SLIDE 4		
SLIDE 5		

Trial 2

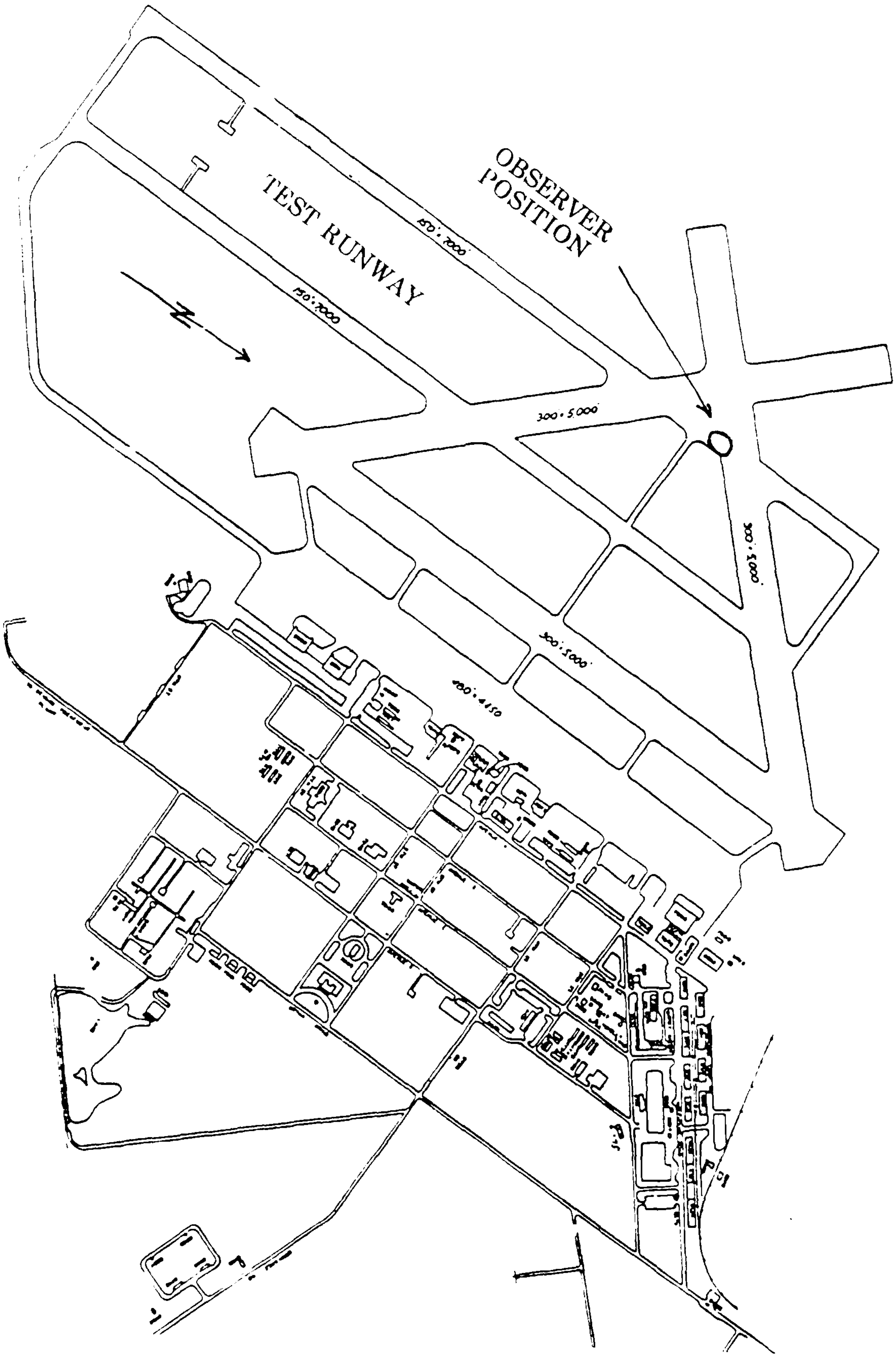
Viewing Condition	ID as object (feet)	ID as car (feet)
BASE		
SLIDE 1		
SLIDE 2		
SLIDE 3		
SLIDE 4		
SLIDE 5		

Trial 3

Viewing Condition	ID as object (feet)	ID as car (feet)
BASE		
SLIDE 1		
SLIDE 2		
SLIDE 3		
SLIDE 4		
SLIDE 5		

APPENDIX D

MAP OF TEXAS A&M RIVERSIDE CAMPUS


OBSERVER
POSITION
TEST RUNWAY

APPENDIX E

PARTICIPANT INFORMATION FORM

Participant Information Form

The following information is needed to enable TTI to study the results of todays experiment.

1. Name:____________________ ID Number: ______________

2. Date of birth: (mm/dd/yr) ____________________

3. How long have you been driving? _______________ years.

4. Do you wear glasses or corrective lenses? (circle one) yes no

APPENDIX F

SUBJECT BRIEFING NARRATIVE

Volunteer Briefing

First, your visual acuity will be measured with a standard Snellen eye chart, then contrast sensitivity will be measured with the chart supplied by Vistech Consultants, Inc. following recommended test procedures. Both measures will be repeated while looking through each slide of simulated spray. Second, we will move to the runway where the actual experimental measurements will be taken. You will be seated in a stationary automobile at the side of the roadway and instructed to look through the simulated spray slides at a target vehicle which will be advancing slowly. An assistant will be in the car to help you with the radio and the simulated spray slides.

Procedure: The target vehicle will start toward you from the extreme end of the runway (approx 1 mile) and will advance at 15 MPH. When you can see some object but cannot identify what it is, say: "**I see it**". When you can identify the object as an oncoming car, say: "**stop**". The car will remain stationary until you have the next slide of simulated spray is in place.

APPENDIX G

PHOTOGRAPHS OF SNELLEN CHART THROUGH SPRAY SIMULATION

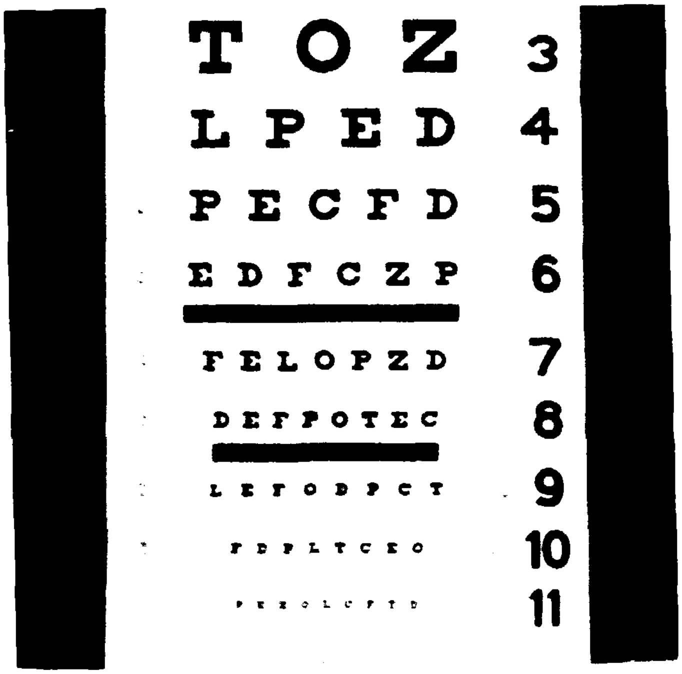


Figure 16. Photo of Snellen Chart Through s1

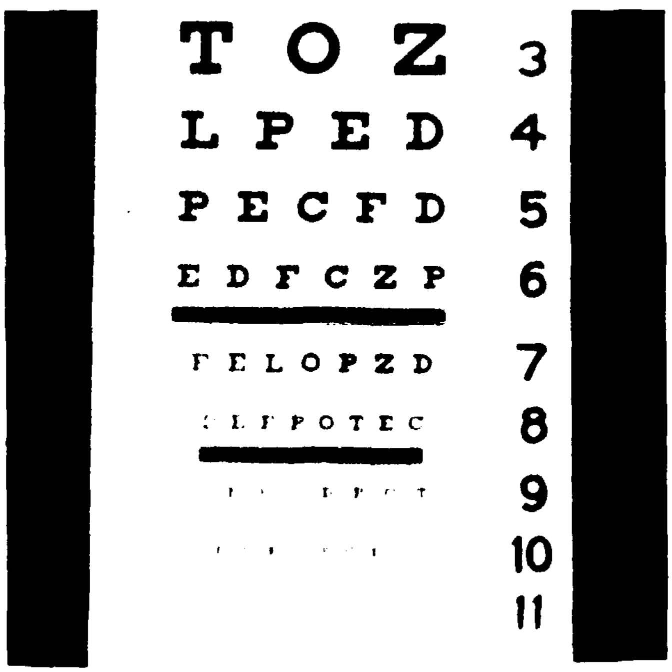


Figure 17. Photo of Snellen Chart Through s2

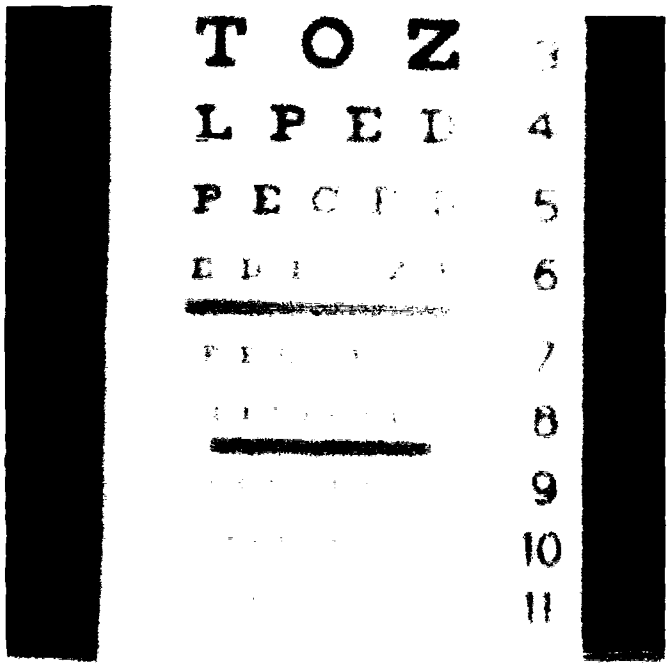


Figure 18. Photo of Snellen Chart Through s3

Figure 19. Photo of Snellen Chart Through s4

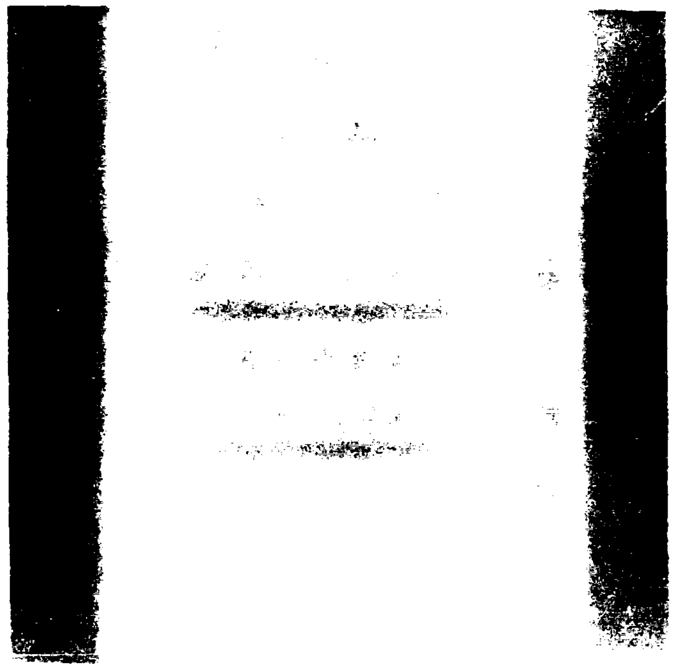


Figure 20. Photo of Snellen Chart Through s5

APPENDIX H

TABULATION OF ALL DATA

Key to data tabulation column headings and entries:

Subject:	Subject identification number.
Slide:	Frame of simulated spray.
Snellen:	Decimal value of measured Snellen acuity.
CS (A):	Level of contrast sensitivity in row A.
CS (B):	Level of contrast sensitivity in row B.
CS (C):	Level of contrast sensitivity in row C.
CS (D):	Level of contrast sensitivity in row D.
CS (E):	Level of contrast sensitivity in row E.
Sum CS:	Sum of values for contrast sensitivity rows A through E.
Raw d1:	Distance target vehicle traveled from starting point before subject identification in first trial.
Raw d2:	Distance target vehicle traveled from starting point before subject identification in second trial.
Raw d3:	Distance target vehicle traveled from starting point before subject identification in third trial.
Raw avg:	Average of raw (1 to 3) distances.
ID feet:	Computed identification distance from subject 5280 - Raw avg = ID feet.
ID meters:	Metric conversion of identification distance ID feet * 0.305 = ID meters.
m:	Missing value

Subject	slide	Snellen	CS (A)	CS (B)	CS (C)	CS (D)	CS (E)	Sum CS	raw d1	raw d2	raw d3	raw avg	ID feet	ID meters
1	base	1.33333	7	7	7	7	6	34	770	540	m	655	4625	1411
1	s1	1	6	6	5	4	3	24	2200	1650	m	1925	3355	1023
1	s2	0.5	6	5	3	2	0	16	2590	2450	m	2520	2760	842
1	s3	0.28571	5	5	2	0	0	12	3890	3250	m	3570	1710	522
1	s4	0.1	3	1	0	0	0	4	4730	4720	m	4725	555	169
1	s5	0.05	1	0	0	0	0	1	5010	4950	m	4980	300	92
2	base	1.33333	6	7	7	5	3	28	1790	1845	1690	1775	3505	1063
2	s1	1	5	5	4	2	1	17	2600	2680	2550	2610	2670	814
2	s2	0.5	5	5	3	0	0	13	3590	3630	3660	3627	1653	504
2	s3	0.28571	4	4	1	0	0	9	4600	4580	4640	4607	673	205
2	s4	0.1	3	1	0	0	0	4	5050	5060	5080	5063	217	66
2	s5	0.05	1	0	0	0	0	1	5180	5180	5210	5190	90	27
3	base	1.53846	6	7	7	7	6	33	680	810	m	745	4535	1383
3	s1	1	6	6	5	4	3	24	1230	1400	m	1315	3965	1209
3	s2	0.5	5	5	3	2	1	16	2450	2680	m	2565	2715	828
3	s3	0.28571	4	4	2	1	0	11	3675	3840	m	3758	1523	464
3	s4	0.2	2	1	0	0	0	3	4870	4880	m	4875	405	124
3	s5	0.1	1	0	0	0	0	1	5110	5100	m	5105	175	53
4	base	1	7	6	6	3	3	25	3530	3200	m	3365	1915	584
4	s1	0.66667	5	6	4	4	1	20	3860	3830	m	3845	1435	438
4	s2	0.5	5	5	3	0	0	13	4300	4280	m	4290	990	302
4	s3	0.2	5	5	1	0	0	11	4550	4630	m	4590	690	210
4	s4	0.1	3	1	0	0	0	4	5050	5040	m	5045	235	72
4	s5	0.05	0	0	0	0	0	0	5180	5180	m	5180	100	31
5	base	0.8	7	7	6	6	5	31	1870	2130	m	2000	3280	1000
5	s1	0.5	6	6	5	3	3	23	2600	3050	m	2825	2455	749
5	s2	0.4	5	5	3	1	0	14	3630	3950	m	3790	1490	454
5	s3	0.2	4	3	2	0	0	9	4425	4830	m	4628	653	199
5	s4	0.1	2	1	0	0	0	3	5110	5070	m	5090	190	58
5	s5	0.05	0	0	0	0	0	0	5200	5170	m	5185	95	29

Subject	slide	Snellen	CS (A)	CS (B)	CS (C)	CS (D)	CS (E)	Sum CS	raw d1	raw d2	raw d3	raw avg	ID feet	ID meters
6	base	1.33333	7	8	7	7	6	35	2190	1590	1350	1710	3570	1089
6	s1	0.8	6	7	6	4	3	26	2600	2500	2400	2500	2780	848
6	s2	0.5	6	6	4	3	0	19	3330	3340	3040	3237	2043	623
6	s3	0.28571	5	5	2	0	0	12	3930	3840	4140	3970	1310	400
6	s4	0.2	3	1	0	0	0	4	4840	4610	4845	4765	515	157
6	s5	0.1	1	0	0	0	0	1	5050	4950	5040	5013	267	81
7	base	1	7	7	7	6	6	33	2250	1060	1860	1723	3557	1085
7	s1	0.8	6	6	4	2	1	19	2470	2490	2650	2537	2743	837
7	s2	0.4	5	5	3	1	1	15	3230	3200	3220	3217	2063	629
7	s3	0.2	5	4	1	1	0	11	4420	4250	4350	4340	940	287
7	s4	0.1	3	1	0	0	0	4	4880	4870	4830	4860	420	128
7	s5	0.05	1	0	0	0	0	1	5090	5115	5130	5112	168	51
8	base	1.33333	6	7	5	5	4	27	1070	500	780	783	4497	1371
8	s1	0.8	6	5	4	2	1	18	2070	2220	2040	2110	3170	967
8	s2	0.4	5	5	3	1	0	14	3195	3170	3360	3242	2038	622
8	s3	0.28571	4	5	1	0	0	10	3740	4320	4460	4173	1107	338
8	s4	0.1	2	1	0	0	0	3	4940	4970	5080	4997	283	86
8	s5	0.05	0	0	0	0	0	0	5150	5190	5210	5183	97	29
9	base	1.33333	6	7	7	7	6	33	2500	1850	2450	2267	3013	919
9	s1	1	5	6	5	4	3	23	3160	3150	3250	3187	2093	638
9	s2	0.5	5	5	3	1	0	14	3795	4020	4150	3988	1292	394
9	s3	0.2	4	4	2	0	0	10	4800	4920	4810	4843	437	133
9	s4	0.1	1	1	0	0	0	2	5135	5160	5150	5148	132	40
9	s5	0.05	0	0	0	0	0	0	5250	5235	5230	5238	42	13
10	base	1	6	7	6	5	4	28	0	0	0	0	5280	1610
10	s1	0.66667	5	6	4	2	1	18	890	565	320	592	4688	1430
10	s2	0.5	5	5	3	1	0	14	2570	1480	1420	1823	3457	1054
10	s3	0.28571	5	4	1	0	0	10	3750	2550	2860	3053	2227	679
10	s4	0.2	2	1	0	0	0	3	4680	4460	4250	4463	817	249
10	s5	0.1	2	0	0	0	0	2	5130	5000	5070	5067	213	65

Subject	slide	Snellen	CS (A)	CS (B)	CS (C)	CS (D)	CS (E)	Sum CS	raw d1	raw d2	raw d3	raw avg	ID feet	ID meters
11	base	1.53846	7	6	7	5	4	29	110	570	260	313	4967	1515
11	s1	0.8	5	5	4	2	1	17	910	980	1070	987	4293	1309
11	s2	0.5	5	5	3	2	0	15	2120	2440	2730	2430	2850	869
11	s3	0.4	4	4	1	0	0	9	3600	3560	3800	3653	1627	496
11	s4	0.1	2	1	0	0	0	3	4980	4900	4920	4933	347	106
11	s5	0.05	1	0	0	0	0	1	5140	5125	5130	5132	148	45
12	base	1.53846	6	7	7	7	7	34	690	1000	500	730	4550	1388
12	s1	1	5	7	6	4	1	23	890	1200	1000	1030	4250	1296
12	s2	0.66667	5	6	3	2	0	16	2370	2010	1950	2110	3170	967
12	s3	0.28571	5	4	1	0	0	10	3670	3250	3610	3510	1770	540
12	s4	0.2	2	1	0	0	0	3	4810	4650	4840	4767	513	157
12	s5	0.1	1	0	0	0	0	1	5010	5015	5060	5028	252	77
13	base	1.53846	7	7	7	7	6	34	1750	1050	860	1220	4060	1238
13	s1	1	6	7	5	4	3	25	2430	2250	1300	1993	3287	1002
13	s2	0.66667	5	5	4	4	1	19	3150	3280	2740	3057	2223	678
13	s3	0.4	4	4	2	0	0	10	4150	4330	3880	4120	1160	354
13	s4	0.2	2	1	0	0	0	3	4870	4770	4630	4757	523	160
13	s5	0.1	1	0	0	0	0	1	5050	5040	5040	5043	237	72
14	base	1.33333	6	7	6	5	5	29	2900	2360	2160	2473	2807	856
14	s1	0.8	6	6	4	2	2	20	3050	2680	2420	2717	2563	782
14	s2	0.5	5	5	3	1	1	15	3750	3360	3250	3453	1827	557
14	s3	0.28571	3	4	1	0	0	8	4460	4320	4500	4427	853	260
14	s4	0.2	3	1	0	0	0	4	4940	4820	4810	4857	423	129
14	s5	0.1	1	0	0	0	0	1	5185	5070	5120	5125	155	47
15	base	1.33333	7	6	6	6	5	30	2000	2010	1000	1670	3610	1101
15	s1	0.8	6	6	4	2	2	20	2000	2280	1690	1990	3290	1003
15	s2	0.5	5	6	3	2	1	17	2550	3520	2160	2743	2537	774
15	s3	0.4	4	4	1	0	0	9	4260	4170	3620	4017	1263	385
15	s4	0.2	2	0	0	0	0	2	4830	4710	4630	4723	557	170
15	s5	0.1	0	0	0	0	0	0	5130	5030	4960	5040	240	73

Subject	slide	Snellen	CS (A)	CS (B)	CS (C)	CS (D)	CS (E)	Sum CS	raw d1	raw d2	raw d3	raw avg	ID feet	ID meters
16	base	1.53846	7	7	6	6	6	32	670	420	260	450	4830	1473
16	s1	1	6	6	4	2	3	21	1250	780	740	923	4357	1329
16	s2	0.5	5	5	3	1	0	14	3150	2000	2550	2567	2713	828
16	s3	0.4	4	2	2	0	0	8	4180	3840	4150	4057	1223	373
16	s4	0.2	1	1	0	0	0	2	4970	4970	4960	4967	313	96
16	s5	0.1	0	0	0	0	0	0	5110	5130	5110	5117	163	50
16	base	1	6	6	5	5	4	26	3480	2970	2950	3133	2147	655
17	s1	0.8	5	6	5	4	2	22	3960	3800	3450	3737	1543	471
17	s2	0.5	5	5	3	2	0	15	4460	4520	4060	4347	933	285
17	s3	0.2	4	4	1	0	0	9	4900	4970	4750	4873	407	124
17	s4	0.1	1	1	1	0	0	3	5120	5140	5060	5107	173	53
17	s5	0.05	0	0	0	0	0	0	5210	5220	5200	5210	70	21
18	base	1.53846	7	7	7	6	5	32	1630	1900	1940	1823	3457	1054
18	s1	0.8	6	6	5	4	3	24	1890	2570	2660	2373	2907	887
18	s2	0.5	5	5	4	2	1	17	3500	3600	3620	3573	1707	521
18	s3	0.4	4	4	2	0	0	10	4340	4580	4460	4460	820	250
18	s4	0.2	3	1	0	0	0	4	4860	5000	5010	4957	323	99
18	s5	0.1	1	0	0	0	0	1	5100	5140	5180	5140	140	43
19	base	1	6	6	5	4	3	24	2550	2800	2940	2763	2517	768
19	s1	0.66667	5	5	4	2	1	17	3060	3260	3250	3190	2090	637
19	s2	0.4	4	4	2	0	0	10	3830	3410	3820	3687	1593	486
19	s3	0.2	2	2	0	0	0	4	4710	4170	4630	4503	777	237
19	s4	0.1	1	0	0	0	0	1	5040	4970	5030	5013	267	81
19	s5	0.05	0	0	0	0	0	0	5190	5140	5170	5167	113	35
20	base	0.8	6	7	6	4	3	26	3110	3060	3300	3157	2123	648
20	s1	0.66667	5	6	5	2	1	19	3560	3900	4150	3870	1410	430
20	s2	0.4	4	5	3	1	0	13	4630	4310	4530	4490	790	241
20	s3	0.28571	3	3	0	0	0	6	4950	4730	4820	4833	447	136
20	s4	0.1	1	1	0	0	0	2	5100	5100	5030	5077	203	62
20	s5	0.05	0	0	0	0	0	0	5200	5200	5150	5183	97	29

VITA

Bruce Alan Wright was born on July 18, 1957 to Earney and Alice Wright, in Oak Park Illinois. He received an Associate of Science degree in Biology from William R. Harper College in Arlington Heights, Illinois in 1980. He was married to Joanna M. Rusin in 1982. After receiving a Bachelor of Science degree in Physiology from the University of Illinois at Urbana-Champaign in 1983, he accepted a commission as a Lieutenant in the U.S. Air Force Biomedical Sciences Corps. While stationed at the Physiological Training Unit on Mather AFB in Sacramento, California, he taught flight physiology to undergraduate aircrew members. In 1986, he was transferred to Brooks AFB, School of Aerospace Medicine in San Antonio Texas, where he conducted research into high altitude and high acceleration physiology as the Chief of Operations for the Crew Systems Branch. In 1988 the Air Force Institute of Technology sent him to Texas A&M University to pursue a Master of Science degree in Industrial Engineering, Human Factors.

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